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A specialist's quoted depth **and the limit order book.(includes related article)**
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TEXT:

A substantial portion of the **market** microstructure literature demonstrates how a specialist uses quoted prices as an instrument to manage inventory, mitigate the adverse selection problem, and promote price discovery. Well-known examples include Garman (1976), Amihud and Mendelson (1980), Glosten and Milgrom (1985), and Leach and Madhavan (1992).

Equally important, but less investigated, is the quantity aspect of a specialist's price schedule. A specialist posts a **bid depth** and an **ask depth** , in addition to the **bid** and **ask** prices, which specify the maximum quantities for which the respective prices apply. Specialists change their quoted **depth** in 90 percent of all quote changes; moreover, 50 percent of all quote changes are unaccompanied by changes in quoted prices. Therefore, specialists actively manage their quoted depths even when prices are not changing.

The primary objective of this paper is to investigate empirically whether specialists use **depth** as a strategic choice variable to regulate the amount of liquidity they provide. Other important suppliers of liquidity, and competitors to specialists, are public limit orders. Given the public order precedence rule (see ??2092 of the NYSE Rules), limit orders at the quoted prices have priority over the specialist's interest. Consequently, to analyze **depth** contributed by the specialist at any point in time, it is necessary to have an estimate of the limit order book that the specialist is maintaining. The difference between the quoted **depth** and the **depth** on the limit order book is the specialist's contribution to **depth** .

The results show that specialists' quotes may reflect only the limit order book on the side (or sides) of the **market** where they believe there is a chance of informed **trading** . By posting a price schedule that mirrors the volume at the

best buy and sell limit order prices, specialists ensure that any trader demanding immediacy will be crossed with limit orders on the limit order book rather than with their inventory. Changes in quoted **depth** are shown to be consistent with specialists managing their inventory positions as well as having knowledge of the future value of the stock. Finally, both specialists and limit order traders reduce **depth** around information events, thereby reducing their exposure to adverse selection costs.

This work is related to a number of areas of ongoing financial research. On the theoretical **front** , early work that addresses the specialist's price schedule takes quantities as exogenous and proceeds to solve for the equilibrium price for each quantity abstracting from any interaction with a limit order book. For example, Easley and O'Hara (1987) find equilibrium prices assuming two possible **trade** quantities, and Kyle (1985) and Glosten (1989) solve for the complete price/quantity function. More recent work by Rock (1996), Kumar and Seppi (1994), and Seppi (1997) advance the basic model by incorporating the interaction between the specialist and the limit order book; yet their models provide no role for the specialist's quoted **depth** . Another tack, taken by Dupont (1995) and Kavajecz (1998), is to start with the assumption that in the absence of a limit order book the specialist posts a price schedule that specifies a **bid** , **bid depth** , **ask** , and **ask depth** . This schedule specifies that the specialist is willing to purchase (sell) shares at the **bid** (**ask**) up to the amount specified by the **bid** (**ask**) **depth** . The advantage of this construct is twofold: it matches the actual price schedules posted on the New York Stock Exchange (NYSE) and it endogenizes the quantity aspect, allowing it to be a choice variable of the specialist. Both Dupont and Kavajecz suggest that one reason a specialist may reduce his **depth** quotes

is to reduce adverse selection costs. The empirical tests in this paper are motivated by the specialist/limit order book interaction of the Rock (1996), Kumar and Seppi (1994), and Seppi (1997) models and the strict specialist price schedule of the Dupont (1995) and Kavajecz (1998) models.(1)

The remainder of the paper is organized as follows. Section I describes the Trades, Orders, Reports and Quotes (TORQ) data set and the procedure used in constructing the limit order book estimates. Descriptive statistics detail the cross-sectional properties of the constructed limit order books, and the interaction between the specialist and the limit order is investigated. Section II analyzes two motives for the specialist's decision to selectively supply liquidity. Section III performs the empirical test of **depth** contribution around information events. Section IV concludes.

I. Limit Order Book

A. Definition

A limit order directs a broker or exchange to purchase (sell) a specified quantity at the best available price not to exceed a maximum (fall below a minimum) acceptable price. A limit order book is a collection of limit orders submitted by traders that is maintained by the exchange (or specialist if at the NYSE) pending execution or further action by the issuers.(2) By submitting a limit order a trader is providing other **market** participants with the ability to execute against his limit order. This is the sense in which limit orders provide liquidity to those who demand immediacy. The limit order book is crucial to the analysis of depths because, as a matter of **trading** protocol, the specialist is required to better any limit order price before he can take the **trade** himself (see ??2092 of the NYSE Rules). To assess whether the specialist or the limit order book is supplying the liquidity in the **market** , one must compare the specialist's quotes with the best limit orders on both sides of the **market** .

At first glance it may be difficult to see why a specialist would ever contribute **depth** above that posted on the limit order book, since he can always decide to improve upon the limit order book at the time of the transaction. There are two countervailing forces against such an incentive. First, in addition to being held accountable by the NYSE for posting a narrow spread, maintaining a continuous price, and stabilizing trades, the specialist also must maintain a reasonable level of **depth** . This requirement causes a specialist to supplement **depth** on the limit order book with his own interest to maintain a "deep" **market** . Second, if the specialist were to merely reflect the interest on the limit order book in his quotes, he would lose the ability to signal or advertise his own interest to the **trading** crowd.

B. Data and Methodology

The TORQ (Trades, Orders, Reports, and Quotes) database covers 144 NYSE-listed securities over the three months from November 1990 through January 1991. As its name suggests, the TORQ data set contains information on all trades that took place, all orders that were placed via one of the automated routing systems, a detailed report of the counter parties to transactions, and the specialist's prevailing quotes.(3) The order data allow for the construction of an estimate of the limit order book. The estimate is incomplete in the sense that the data only include orders that are placed through one of the automated routing systems. Orders brought to the floor via a floor broker are not included, but this omission does not bias the results or conclusions. Firms are separated into deciles with 15 in each of the first four deciles and 14 in each of the six remaining deciles. Stocks are ranked by average daily **trading** volume over the sample period.(4)

The TORQ database contains three major types of records regarding limit orders: orders, executions, and cancellations. Each order record specifies, among other things, the date and time of submission, the type of order, the order quantity, and the limit price. Execution and cancellation records provide similar information about the underlying order as well as information specific to the execution or cancellation, such as the execution (cancellation) date and time and quantity executed (canceled). The principle behind the limit order book estimation is that at any instant in time the limit order book should reflect those orders remaining after

the orders placed prior to the time in question are netted with all prior execution and cancellation records.

The estimation is done in four steps. The first step entails the identification of existing limit orders at the time the sample started; these are limit orders submitted prior to November 1, 1990, which up to that point had not been executed or canceled. I call this the prebook. Because the orders sought were placed prior to the start of the database, there are no corresponding order records included in the database. Instead, I must infer the existence of the order from subsequent execution and cancellation records. The prebook is constructed by searching over all available records for a given stock and retrieving any execution or cancellation records that refer to an order placed prior to the start of the sample period. Those records are then converted into order records making up the existing limit order book at the beginning of the sample period.

After the prebook is constructed, current records in the database are processed. To estimate the limit order book for a given date and time, all records with a date and time stamp prior to the chosen date and time are selected and separated into their respective categories: orders, executions, and cancellations. The second step in the procedure adds the current orders to the prebook; the result is a listing of all known orders placed prior to the chosen date and time.

Step three entails matching order records with execution records. Recall that execution records contain all the information about the underlying order. This makes it possible to determine which orders were executed. Those orders having matching execution records are eliminated. The remainder are orders or residual orders that were unexecuted prior to the chosen date and time.

The last step performs the analogous procedure using cancellation records. Current cancellation records are matched with the remaining order records and any order with a matching cancellation record is eliminated.(5) The remaining order records are orders that were placed prior to the chosen date and time and were not executed or canceled in entirety.(6) These remaining records constitute the limit order book estimate for the chosen stock at the chosen date and time.

Not all the execution and cancellation records match up to orders as they should. Moreover, orders remain on the limit order book that clearly should have been either executed or canceled. An example of this problem is when there is a buy order on the limit order book that is above the posted **ask** . This scenario would warrant immediate execution of the "misplaced" order. Problem records such as these are eliminated. These problems could have arisen from typographical errors or missing records, both of which would make matching records impossible. Table I shows the average number of records processed for each decile and the average percentage of each record type that is discarded. Analysis on an individual stock basis is shown in the last two rows. The median stock has less than one-half of 1 percent (0.48 percent) of its records discarded, with the worst case discarding 4.17 percent of its total records. The fact that the vast majority of the records match up exactly suggests that the procedure provides a fairly clean estimate of the limit order book. Limit order books are estimated at 30-minute intervals for all 63 business days in the sample period, yielding a maximum of 882 limit order book estimates for each of the 144 stocks in the sample.(7) For an example of a particular limit order book estimate, see the Appendix.

C. Summary Statistics

This subsection investigates the amount of liquidity provided by the limit orders on the NYSE. For instance, do the limit order books have sufficient shares to be meaningful providers of **depth** ? Table II shows the aggregate amount of **depth** provided by the limit order book. The table displays the average number of orders and the average total volume expressed both in (TABULAR DATA FOR TABLE I OMITTED) shares and as a percentage of average daily **trading** volume. On average, there are 10,000 shares or more on each side of the limit order book for all but the smallest stocks.(8) Even though the smaller stocks have fewer shares on their limit order books, they are able to accommodate a much larger fraction of average daily **trading** volume than are the larger stocks. The average number of orders implies that the limit order books are made up of

increasingly larger orders as the stocks get smaller (less frequently traded).

Although the limit order books seem to provide a good deal of **depth**, what really matters is the amount of **depth** provided at the **market**. It is this **depth** that is crucial when comparing the specialist's **depth** quotes with the book. Table II also describes the **depth** at the best **bid** and **ask** limit prices. As a percentage of the total volume on the book, **depth** at the **market** ranges from 9 percent to 50 percent. Interestingly, the percentage of **depth** at the **market** is larger for the stocks with the lowest average daily **trading** volume.

(TABULAR DATA FOR TABLE II OMITTED)

Table III presents a comparison of the spread on the limit order book as well as the dispersion of shares away from the best prices. The spread between the best buyside and sellside limit orders can be very large, both in terms of dollars and percentages, averaging $0.73 or 7.96 percent across all stocks. Contrast that with the specialist's quoted spread, which averages $0.23 or 3.96 percent. This suggests that the specialist plays an important role in narrowing the spread that **market** participants face when demanding liquidity, especially for smaller (less frequently traded) stocks.

The first and last columns of Table III **display** the dispersion of volume on the buyside and sellside of the book. The dollar dispersion on the buyside of the book is the dollar difference between the best buyside limit order price (TABULAR DATA FOR TABLE III OMITTED) and the volume-weighted average limit price on the buyside of the book. The dollar dispersion on the sellside is defined analogously. The percentage dispersion is the dollar dispersion divided by the limit order book's **bid** - **ask** midpoint. Notice that the buyside has a dispersion of $1.55 or 9.53 percent and the sellside has a dispersion of $1.66 or 24.63 percent. Although the difference between the percentage dispersions is significant at the 0.1 percent level it may simply be an artifact of the stock price being bounded at zero on the buyside and unbounded on the sellside.

D. Specialist Interaction

The relation between the best prices and quantities on the limit order book and the specialist's posted quotes is crucial to understanding who is providing liquidity. A specialist's strategy of quoting the same price and the same **depth** as the best buyside (sellside) limit order insulates the specialist from any informed traders wishing to sell (purchase) shares because the specialist is able to pass the order through to cross with the limit order book. This behavior eliminates unwanted trades, thereby reducing the specialist's exposure to adverse selection costs.

Table IV presents data on how often specialists position their quotes in this way. The results are partitioned into four cases. Column i shows the percentage of time when the specialist's prices are inferior to the best limit (TABULAR DATA FOR TABLE IV OMITTED) order on the buyside and sellside. This column depicts instances when there are hidden limit orders. By posting a **bid** (**ask**) that is lower (higher) than the best buyside (sellside) limit order, the specialist hides the existence of these orders from other **market** participants. Column 2 shows the percentage of time that the specialist posts a price equal to the best limit order and a **depth** quote that is less than or equal to the volume of shares on the book at that price. Here, the specialist's quotes reflect only the interest on the limit order book, making the specialist immune to any adverse selection costs. Column 3 shows the percentage of time that the specialist posts the same price as the best limit order and the posted **depth** is set greater than the volume on the book at the best limit order. The difference between the quoted **depth** and the **depth** on the book is the additional **depth** provided by the specialist.(9) Column 4 shows the percentage of time that the specialist posts a better price than that on the limit order book. In these cases, the specialist is providing 100 percent of the **depth** at the **market**.

On one hand, Table IV shows that the specialist is either providing additional **depth** or bettering the price 50 to 75 percent of the time. On the other hand, 25 to 50 percent of the time the specialist effectively removes himself from one side of the **market**; therefore, the specialist is selectively providing liquidity and selectively protecting himself from the

market .(10) Columns 5 and 6 give information on the **depth** provided by the limit order book and specialist respectively. The **depth** values are an average of the number of shares pledged by the limit order book and the specialist at the best available price, regardless of whether the best price is posted or hidden. For example, if the specialist is hiding a 1,000-share limit order, the specialist's contribution to **depth** is zero and the contribution from the limit order book is 1,000. Moreover, if the specialist is bettering the limit order book by an eighth, the limit order book contribution to **depth** is zero and the contribution from the specialist is the posted **depth** . These columns reveal that both the limit order book and the specialist provide essential liquidity to the **market** . The **depth** contributions for both the limit order book and the specialist tend to decrease as the stocks become smaller (less frequently traded). Owing to a sharper reduction in contributed **depth** by the specialist, the book provides more of the **depth** for the smaller (less frequently traded) stocks and the specialist provides more of the **depth** for the larger (more frequently traded) stocks. This is consistent with the idea that smaller (less frequently traded) stocks tend to have both higher inventory costs and greater risks of informed **trading** ; therefore, the specialist protects himself by reflecting the interest in the limit order book more often.

It is clear that all liquidity providers, specialists and limit order traders alike, have an incentive to shy away from orders carrying high adverse selection and inventory costs. For those limit order traders that remain to supply liquidity to the smaller (less frequently traded) stocks there are two possibilities: they have to **trade** or they are informed. Traders needing to transact in thinly traded stocks may prefer to submit "at-the-quote" limit orders in order to avoid paying the wide **bid** - **ask** spread. The same argument can be made if the liquidity provider is informed. Given the thinness of the **market** for small stocks, informed traders might prefer to use "at-the-quote" limit orders to execute their trades, thereby eliminating the **bid** - **ask** spread. Moreover, the strategy may allow the informed trader to better conceal his information.

II. The Specialist's Motives

What remains to be answered is when and why a specialist might refrain from adding **depth** to the **depth** on the limit order book. This section focuses on two possible rationales for this behavior. First, the specialist may actively manage his inventory position by taking on larger buy orders and/or curtailing sell orders if his inventory is too short or by taking on larger sell orders and/or curtailing buy orders if his inventory is too long. Second, the specialist could be informed about the direction of the stock price. Positioning the price schedule to reflect the limit order book on the sellside as well as adding **depth** on the buyside when the stock is undervalued shields the specialist from being the counter party to informed traders and simultaneously positions the specialist to purchase undervalued shares. Positioning the price schedule using the opposite strategy would exploit an overvalued stock. These two possible rationales are investigated in turn.

Tests of inventory management cannot be performed directly due to a lack of inventory data, therefore any test must condition on some observable variables that impact the specialist's inventory position. One simple conditioning rule would be to condition on changes in the posted **bid** and **ask** . Consider the following scenario. Suppose prices have been rising due to buying pressure or falling due to selling pressure, and assume that the specialist has been providing at least some of the liquidity. Then over this period, the specialist's inventory position would be reduced if prices were rising and increased if prices were falling. Actions that are consistent with inventory management are for the specialist to reflect the sellside of the limit order book (add **depth** to the **bid** side only) after prices have been rising to curtail further reductions in his inventory and to reflect the buyside of the limit order book (add **depth** to the **ask** side only) after prices have been falling to curtail further increases in his inventory.

Table V conditions the limit order book/quote sample on two consecutive prior price increases (columns 1-4) and decreases (columns 5-8). The table provides a breakdown of the sample by whether the specialist is reflecting the limit order book on both sides, the sellside (**ask** side), the buyside (**bid** side), or whether the specialist is adding

liquidity on both sides of the **market** . Comparing the specialist's quotes after rising prices to those after falling (TABULAR DATA FOR TABLE V OMITTED) prices reveals that although there is little difference in the percentage of times the specialist is reflecting both sides or neither side of the limit order book, there is a difference between the percentage of time the specialist reflects either the sellside or the buyside.

Consistent with the inventory management scenario, the specialist is more likely to reflect the sellside of the book (add **depth** to the **bid** side only) when prices in the previous hour were rising and is more likely to reflect the buyside of the book (add **depth** to the **ask** side only) when prices in the previous hour were falling. The difference between the percentage of time the specialist is reflecting the sellside (buyside) after rising prices and the percentage of time the specialist is reflecting the sellside (buyside) after falling prices is significant at the 0.1 percent (0.5 percent) level. These results are consistent with Hasbrouck and Sofianos (1993), Madhavan and Smidt (1993), and Madhavan and Sofianos (1994), who collectively find evidence of inventory management by specialists. The results shown here serve to reinforce the argument made by Madhavan and Sofianos that inventory management is a passive pursuit of the specialist and is often accomplished "by selectively timing the magnitude and direction of their trades rather than by adjusting prices."

The other possible reason for the specialist to refrain from adding **depth** to the **depth** on the limit order book is information about the future value of the stock price. The idea that the specialist is well informed about the value of the stock is not a new one. Benveniste, Marcus, and Wilhelm (1992) argue that the specialist often has very good information about the **market** participants and what they know about the underlying value of the asset. Reviewing Table V in light of the information hypothesis reveals that although it is consistent with the inventory hypothesis it is also consistent with the information hypothesis. Curtailing sales and promoting purchases after rising prices and curtailing purchases and promoting sales after falling prices help the specialist avoid being the counter party to unprofitable (informed) trades as well as take on profitable (uninformed) trades.

Although Table V provides insights into the information hypothesis, it is a coarse test because conditioning on price changes means that only a subset of the limit order book/quote sample is used. Table VI presents a more refined and comprehensive test of the information hypothesis that utilizes the full sequence of limit order book/quote data to infer whether the position of the specialist's quotes reveals anything about future prices. The test involves a **trading** strategy based solely on the position of the specialist's quotes relative to the limit order book. The interpretations of the quote positions are as follows: Under the information hypothesis, if a specialist adds **depth** only to the buyside of the limit order book, then he is unwilling to sell shares but is willing to buy shares. His quote position reveals that the stock is undervalued. Similarly, if a specialist adds **depth** only to the sellside of the limit order book, then he is unwilling to buy shares but is willing to sell shares. His quote position reveals that the stock is overvalued.

In the spirit of Handa and Schwartz (1996) the test involves placing hypothetical orders according to the specified **trading** strategy, assuming the orders leave the **trading** environment unchanged, and maintaining the portfolio until it is liquidated. Specifically, the strategy entails checking the position of the specialist's quotes relative to the book each half-hour throughout the day. If the specialist has reflected only the sellside of the book for the past three consecutive half-hour periods and the current inventory position is nonpositive, cover any inventory and buy 50 shares. If the specialist has reflected the buyside of the book for the past three consecutive half-hour periods and the current inventory position is nonnegative, liquidate any inventory and sell 50 shares, otherwise maintain the current inventory position.(11) Given that the only information the strategy utilizes is the position of the specialist's quotes relative to the book, if the strategy is profitable it implies the specialist has information about the direction of future prices. The advantage to using such a **trading** strategy is that it allows for the holding period to vary and it quantifies the potential **trading** profits.

Admittedly, this strategy cannot be implemented in practice. First,

it assumes that the trades made by this strategy do not affect prices or depths. Second, the specialist would need to reveal the position of his quotes relative to the limit order book each half-hour. Third, there are no constraints on short-selling. Fourth, both the discount rate and borrowing rate are zero percent. It should be stressed however, that the purpose of this strategy is (TABULAR DATA FOR TABLE VI OMITTED) not to provide a profitable real-world **trading** strategy but, rather, to test whether the position of the specialist's quotes reveals anything about future prices.

Panel A of Table VI summarizes the results from the posited **trading** strategy when trades are crossed with the specialist's quotes. In this panel, purchases are executed at the specialist's **ask** and sales are executed at the specialist's **bid** . The strategy is constructed to ensure that the maximum **trade** size (100 shares) is never greater than the minimum posted **depth** . The table presents information on the number of trades, the shares traded, the mean and median profit per share, the mean and median total profit, and the number of profitable stocks in each decile. The results show overwhelmingly that the strategy is unprofitable. For each decile both the median profit per share and total profit are negative. For only 13 percent of the stocks in the sample is this a profitable strategy; however, notice that the median loss per share is approximately the size of the **bid** - **ask** spread for each of the deciles. By having the strategy buy at the **ask** and sell at the **bid** , the loss associated with the **bid** - **ask** spread is implicitly built into the results. Panel B performs the **trading** strategy again using the same **trading** rules except this time it executes all transactions at the midpoint of the posted **bid** and **ask** in order to eliminate the cost of the **bid** - **ask** spread. The results in Panel B are an improvement over those in Panel A. The full sample results show a mean (median) per share loss of approximately one-sixteenth, $0.10, ($0.03) and a mean (median) loss over the three-month period of $66 ($23). Although the mean per share loss is not significantly different from zero, the mean total loss is significantly different from zero at the 5 percent level. Despite the aggregate results continuing to show a loss associated with this strategy, 37 percent of the sample generated a profit. The percentage of profitable stocks increases to 47 percent if we focus on the largest four deciles. Contrary to the results in Panel A, those in Panel B provide some evidence in favor of the information hypothesis, especially for the larger (more frequently traded) stocks. The results demonstrate that the position of the specialist's quotes relative to the limit order book can provide information about the direction of changes in the **bid** - **ask** spread midpoint. Because the specialist is setting the quotes, he must have some information about the direction of these changes. The results are consistent with work by Hasbrouck and Sofianos (1993) which shows that specialists' profits are generated primarily from short- and medium-term holding periods (fewer than 100 transactions). Although they demonstrate that the bulk of specialists' profits are generated from the **bid** - **ask** spread, they are able to identify a small but significant component of specialists' profits over the medium term (10 to 100 transactions) related to specialists' ability to anticipate price reversals over this horizon.

In summary, this section reveals that the use of **depth** as a strategic variable is a widespread phenomenon. Specialists position their quotes to reflect the interest in the limit order book in order to avoid being the counter party to incoming trades. The investigation into the rationale for the specialist's actions provides evidence consistent with both the inventory management hypothesis and the information hypothesis.

III. Statistical Tests of **Depth** Contribution at Information Events

The posited hypothesis is that liquidity providers, specialists in particular, reduce their contribution to **depth** in order to minimize the costs of **trading** with **market** participants who possess more information. This is not the first time researchers have investigated this aspect of liquidity provision. Lee, Mucklow and Ready (1993) investigate changes in price schedules surrounding earnings announcements and Foster and Viswanathan (1994) and Jennings (1994) investigate changes in price schedules surrounding takeover announcements. The empirical work in this paper is most closely related to that of Lee et al. (1993) because they also study how depths and prices interact as well as the role quoted **depth** plays in determining overall liquidity. They show that liquidity providers

tend to coordinate prices and quantities, with large spreads being associated with lower depths; therefore, it is necessary to consider both prices and depths in order to assess overall liquidity. Their test of quoted **depth** reveals that liquidity providers anticipate adverse selection problems by widening spreads and lowering depths prior to earnings announcements.

This work builds on the work of Lee et al. (1993) in a number of ways. First, they are unable to distinguish between **depth** on the limit order book and **depth** provided by the specialist. Their results speak to aggregate liquidity provided; the work done here can determine who is providing the liquidity and when. Second, their measure of **depth** is the sum of the **bid depth** and the **ask depth** ; therefore, even though their results suggest that aggregate **depth** falls, their work does not allow an individual analysis of each side of the **market** . Moreover, since earlier evidence shows that the specialist may be informed about the direction of the stock price, testing the theory on both the **bid** and the **ask** side uniformly may provide misleading results. The real question is whether the liquidity provider (specialist) uses depths to protect himself where he thinks there is a chance of informed **trading** . In the case of earnings announcements, if the announcement is bad news the test examines whether the liquidity provider's **bid depth** is small, and if the announcement is good news the test examines whether the liquidity provider's **ask depth** is small. The opposite side of the **market** may or may not have low **depth** depending on whether the liquidity provider is privy to any information about the announcement. Lastly, the test is expanded to include other information events besides earnings announcements; specifically, monetary policy announcements made by the Federal Reserve's Federal Open **Market** Committee (FOMC) are considered. Fortunately, over the time span of the TORQ sample the FOMC eased monetary policy by lowering the Federal Funds rate 25 basis points on four separate occasions.(12)

The empirical test is an event study around the relevant information event, either earnings announcement or FOMC announcement. Of the 144 stocks in the TORQ database, 88 have earnings announcements within the sample period, and 83 make up the final sample used in the earnings announcement study, whereas 143 of the stocks are included in the FOMC announcement study.(13) As with all event studies, it is imperative that the exact date and time of the event is known. In the case of earnings announcements, the dates and times were obtained from the Dow Jones News Service Broadtape. The Broadtape provides the reported earnings prior to any subsequent corrections as well as the announcement date and time to the nearest minute. The timing for each of the FOMC announcements is 11:35 a.m. EST. The reason for the similarity in the timing of the FOMC announcements is that during this time period monetary policy changes and, more specifically, changes in the desired Federal Funds rate were signaled to the **market** through daily open **market** operations rather than direct public announcement. These operations are conducted each day between 11:30 a.m. and 11:35 a.m. EST.

In addition to determining the timing, earnings announcements must be classified as either "good" or "bad" relative to the **market** 's expectation in order to test the appropriate side of the **market** . The latest Value Line forecast is used as the proxy for the **market** 's expectations. Earnings announcements are classified by whether the actual earnings announcement is higher or lower than the latest Value Line forecast. Not all of the announcements in the sample are followed by Value Line; in those instances the announcement is compared to the respective earnings one year earlier.(14) Of the 83 announcements, 48 are categorized as "bad" and 35 are categorized as "good" announcements.

The statistical test involves using an estimate of the empirical distribution to determine if the **depth** contribution around the announcement is small relative to the contribution in the whole sample. The advantage of bootstrapping the empirical distribution is that it is free from error caused by an incorrect distributional assumption. The test is performed as follows. For each stock, the empirical distribution of the specialist's **depth** contribution, the limit order book's **depth** contribution, and the quoted **depth** are constructed on each side of the **market** separately. Each of the six distributions is made up of 1,000

sample points. Each sample point is an average of a sequence of 14 observations whose beginning point is chosen at random from the relevant **depth** sequence. Choosing a sequence of points helps to account for any serial dependence present in the time series of depths. After constructing the six empirical distributions, the **depth** contribution around each announcement is calculated. For each announcement, a preannouncement and a postannouncement observation are calculated. The preannouncement observation is the average of the **depth** contribution during the day immediately preceding the announcement (14 observations); analogously, the postannouncement observation is the average of the **depth** contribution over the day immediately following the announcement (14 observations). Lastly, each announcement period observation (pr e- and post-) for each of the six **depth** sequences (specialist, limit order book, and quoted **depth**) is compared to its respective empirical distribution. For each announcement observation the probability of drawing a sample point that is lower than the announcement observation (p-value) is computed.

A. Results

The test results are displayed in Tables VII and VIII. The tables report the results for the specialist, limit order book, and posted quotes for both the preannouncement period (Panel A) and the postannouncement period (Panel B). The values represent the fraction of the announcement observations that fall in the lowest portion of their respective empirical distribution. For example, the first column displays the fraction of announcement observations that fall in the lowest 5 percent of their respective distributions. Correspondingly, each row represents the cumulative distribution of the cross section of announcement observation p-values.

Table VII reports the results for the earnings announcement tests. Each announcement is segmented into the side of the **market** that goes with the announcement (labeled "With") and the side of the **market** that goes against the announcement (labeled "Against"). For example, if the announcement is a good announcement in the sense that it exceeds expectations, then the **ask** side (sellside) of the **market** is labeled "With" and the **bid** side (buyside) is labeled "Against." If the announcement is bad in that it does not meet expectations, then the **bid** side (buyside) is labeled "With" and the **ask** side (sellside) is labeled "Against." This labeling procedure allows the sides of the **market** to be grouped by their relation to the direction of the announcement rather than by whether the orders are buy or sell orders. Given the earlier evidence that specialists may be informed about the future stock price, and therefore may only react on one side of the **market** , the hypothesis predicts a reduction in the **depth** contribution by liquidity providers on the side of the **market** labeled "With."

The reported values provide a number of interesting results. First, a substantial number of the preannouncement period depths are small compared to their respective distributions as seen by the cumulative distributions skewed to the left, especially for the posted quotes and the limit order book. As an example, 28.4 percent of all the limit order books' preannouncement period depths in the direction of the announcement are located in the lowest 20 percent of their respective distributions. Second, the **depth** contributions increase substantially after the announcement as seen by the increase in the **depth** contributions of all liquidity providers in the postannouncement period. Third, although both sides of the preannouncement period posted quotes are small relative to their distribution, there is more of a reduction in the **depth** in the direction of the announcement which is consistent with the specialist having some knowledge of the future price.

(TABULAR DATA FOR TABLE VII OMITTED)

The direct evidence on the specialist's **depth** contribution is less convincing. The specialist's results suggest that the **depth** contributions prior to an earnings announcement, although somewhat smaller, are largely in line with their empirical distribution. It is important to note however, that most of the deviations from the null hypothesis occur in the leftmost portion of the cross-sectional distribution. This suggests that although the earnings announcement is an important information event for some stocks, for others it is not. This result may be a function of the inability to completely **screen** out cases where the information has

effectively "leaked," leading the earnings announcement date as a noninformation event.

In summary, the results provide evidence for the posited hypothesis in that, to a lesser extent, the specialist and, to a greater extent, the limit order book reduce their respective contributions to **depth** around the time (TABULAR DATA FOR TABLE VIII OMITTED) of an earnings announcement. Moreover, **depth** contributions by liquidity providers increase after the announcement is made. Finally, there is evidence that the quotes are lower in the direction of the announcement, reinforcing the idea that the specialist has some information about the pending announcement. These results are consistent with those reported by Lee et al. (1993) as well as by Foster and Viswanathan (1994) and Jennings (1994) who find low quoted **depth** prior to takeover announcements and a marked increase in quoted **depth** after takeover announcements.

The other information events that are tested are FOMC announcements concerning the desired Federal Funds rate. These FOMC announcements are an interesting complement to the earnings announcements because interest rate changes, unlike earnings announcements, allow an analysis of the effects of volatility without the confounding effects of asymmetric information.

Observations for the January 9, 1991, FOMC announcement are reported in Table VIII.(15) Contrary to the preceding table, Table VIII segments the results into **bid** and **ask** sides. These results are similar to the earnings announcement results in that there are substantial numbers of very small **depth** contributions for the specialist, limit order book, and posted quotes. For the preannouncement period, the specialist's contribution is lowest on the **bid** side and the limit order book's contribution is lowest on the **ask** side. As an example, 28.7 percent (20.3 percent) of the specialists' preannouncement period **bid** (**ask**) depths fall in the lowest 20 percent of their respective distributions. In the postannouncement period the situation reverses itself: specialists restrict **depth** at the **ask** and the limit order book restricts **depth** at the **bid** . Moreover, the postannouncement period shows increases in **depth** contribution for both the specialist and the limit order book, although the increase tends to be smaller for the specialist. These results demonstrate that in addition to managing depths to mitigate adverse selection problems, liquidity providers also manage depths to minimize the uncertainty associated with volatility **trading** periods.

Admittedly, the statistical results are clouded by some unavoidable difficulties associated with this test. First, the test focuses on two uses specialists may have for **depth** : reducing adverse selection costs or reducing the uncertainty associated with periods of volatile **trading** . There are, however, other uses that are not accounted for. For instance, the specialist may use quoted **depth** to manage inventory or to promote price discovery. These effects, if counter to reducing adverse selection costs or reducing volatility costs, would tend to mask the significance of these results. Unfortunately, controlling for these effects is not possible due to a lack of data. Second, information events occur all the time. To the extent that other announcements occur simultaneously, especially for earnings announcements which are made at varying dates and times, the test cannot hope to compare the earnings announcement separately from a noninformation event period. Rather, both the announcement period **depth** and the empirical distribution incorporate the effect of other information events. Third, orders not placed through one of the automated routing systems are missing from the limit order book estimates. This may cause a misestimation (overstatement) of the **depth** that the specialist is providing. For example, suppose a limit order is brought to the **trading** post by a floor broker for 10,000 shares at nine dollars and the order happens to be the best limit order on the sellside of the limit order book. This order is not included in the data because it was not submitted through one of the automated routing systems. If the specialist is posting an **ask** of nine dollars and an **ask depth** of 10,000 shares then in reality the specialist is supplying no **depth** . However, because the limit order book estimates lack the information on this order, the specialist would be credited with supplying a **depth** of 10,000 shares. This may be one reason some of the announcement observations are unusually large relative to the unconditional distribution. Even with the associated problems with the test and the data, the results still present strong evidence for the hypothesis

that liquidity providers reduce contributed **depth** prior an information event in order to reduce adverse selection costs or reduce the costs associated with volatile **trading** periods.

IV. Conclusion

This paper demonstrates that depths are used as a strategic choice variable by the specialist. Specifically, by lowering the **depth** quotes to reflect only the interest in the limit order book, the specialist can pass off unwanted trades onto the limit order book. Furthermore, evidence is presented that supports both inventory concerns as well as adverse selection/information concerns as the catalyst behind the specialist's actions. Finally, the statistical tests show that liquidity providers reduce their contribution to **depth** around the time of an information event, whether it is to reduce adverse selection costs in the case of earnings announcements or reduce the costs associated with volatility in the case of FOMC announcements.

Appendix

The following exhibit is the estimated limit order book for Federal Express on November 21, 1990, at 12:00 noon. The exhibit is organized with sell orders in the upper left corner and buy orders in the lower right corner. The limit orders are listed in increasing price/time priority on the **ask** side and decreasing price/time priority on the **bid** side. Each order specifies the date and time (if known) of placement, the side of the **market** (regular sell orders (SEL), short-sales (SST), and buy orders (BUY)), the duration of the order (good-until-canceled (GTC) and DAY), the number of shares, and the limit price. (The time of placement is not known for orders placed prior to the start of the database.) Between the buy and sell limit orders the prevailing NYSE quote and the best non-NYSE quote are listed. The quotes **display** the **ask depth** , **ask** , **bid** , and **bid depth** , respectively.

The specialist is providing liquidity only on the **bid** side of the **market** . On the sell side, the two best limit orders at 32 3/8 totaling 2,100 shares are more than the **ask depth** posted by the specialist. In contrast, the specialist is posting a **bid depth** of 5,000 shares, 1,100 of which are attributed to the limit order book. The additional 3,900 shares are attributed to either the specialist or floor traders.

(TABULAR DATA FOR EXHIBIT A.I OMITTED)

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1 There is also a growing empirical literature on limit order books; however, this literature's primary focus has been pure limit order book markets rather than specialist markets. Examples include: Niemeyer and Sandas (1993), Stockholm; Hedvall (1994), Helsinki, Lehmann and Modest (1994), Tokyo; Niemeyer (1994) Helsinki/Stockholm; Biais, Hillion and Spatt (1995), Paris; Frino and McCorry (1995), Australia; Hamao and Hasbrouck (1995), Tokyo; de Jong, Nijman and Roell (1995), Paris; Hollifield, Miller, Sandas (1996), Stockholm; and Sandas (1998), Stockholm.

2 The limit order book is so named because originally it was a ledger that the specialist carried to log limit orders.

3 These data do not give an estimate of the specialist's inventory.

4 Decile rankings are also done using CRSP data on **market** capitalization at the 1990 year **end** . Although the results are largely the same under either ranking mechanism, **trading** activity seems to be a better predictor of limit order book properties.

5 Executions are handled before cancellations because execution records provide more fields to match with the original order; therefore, it is harder to mismatch an execution than it is to mismatch a cancellation.

6 There are partial executions and partial cancellations. This entails an execution or cancellation of a fraction of the original order, where the residual order remains as an active limit order.

7 Estimates are calculated at the time of the opening quote and each half-hour on the half-hour thereafter. For example, if a stock opens at

9:40:28 a.m., an estimate is taken at that time and then estimates are done at 10:00:00, 10:30:00, etc. The number of limit order books for each stock is approximate because occasional late openings (later than 10:00:00) cause differences in the number of estimates for each stock.

8 The significantly larger volume in the "Large" decile is driven by six stocks: Boeing (BA), General Electric (GE), International Business Machines (IBM), Philip Morris (MO), American Telephone and Telegraph (T), and Exxon (XON). These are the only stocks in the sample included in the Dow Jones Industrial Average.

9 Greene (1996) provides an algorithm to infer transactions crossed with the limit order book. Assuming the specialist is likely to adjust his **depth** quote when he is reflecting some portion of the **depth** on the limit order book and that **depth** is subsequently altered, we see that the percentages obtained from summing columns 1, 2, and 3 of Table IV are broadly in line with the 77.36 percent (mean) and 50 percent (minimum) success rate of his algorithm.

10 Cao, Choe, and Hatheway (1997) and Corwin (1998) argue that there are important differences in the behavior of specialist firms. In principle, differences in the choice to reflect the limit order book in the posted price schedule could be driven by this effect; however, 34 specialist firms are represented in the TORQ sample with no one specialist firm maintaining a majority in any one decile.

11 The **trading** strategy is also executed conditioning on two and four consecutive half-hour periods. The results are both qualitatively and quantitatively similar to the results shown.

12 Open **market** operations were conducted to implement a reduction in the Federal Funds rate of 25 basis points on November 14, 1990, December 7, 1990, December 19, 1990, and January 9, 1991. The movement on December 19, 1990, was accompanied by a reduction in the discount rate of 50 basis points. Of further note is that Federal Open **Market** Committee meetings were held on November 13, 1990, and on December 17 and 18, 1990.

13 There are various reasons for eliminating stocks. I am unable to determine the exact time of the announcement for one of the stocks. Two stocks, one having its announcement on November 1, 1990, and the other on January 31, 1991, have insufficient observations before or after the announcement to properly perform the test. The remaining two stocks are eliminated because the firms preempted the official announcement with a preliminary announcement.

14 Value Line forecasts were unavailable for 17 (20 percent) of the 83 stocks.

15 Results for the other three FOMC announcements are similar to those shown in Table VIII but are not shown for brevity. The January 9, 1991, announcement was chosen for **display** for two reasons. First, announcements made on November 14 and December 19 follow scheduled FOMC meetings and could have been anticipated by the **market** , those on December 7 and January 9 provide cases with potentially more uncertainty. Second, fewer of the earnings announcements occur in January than either in November or in December, making January a period with the fewest competing announcements.

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### Status: Signing onto Dialog
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ENTER PASSWORD:
 ******** HHHHHHHH SSSSSSSS? ********
Welcome to DIALOG
### Status: Connected


Dialog level 03.06.02D

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Logon file405 13jan04 11:18:20
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GURU2 is set ON as an alias for 9,623,810,624,636,813,634,20.
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* * * ALL NEW CURRENT YEAR RANGES HAVE BEEN * * *
* * * INSTALLED   * * *
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Cost is in DialUnits
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 Information:
  1.  Announcements (new files, reloads, etc.)
  2.  Database, Rates, & Command Descriptions
  3.  Help in Choosing Databases for Your Topic
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Enter an option number to view information or to connect to an online
 service.  Enter a BEGIN command plus a file number to search a database
(e.g., B1 for ERIC).
?b 411

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File 411:DIALINDEX(R)

DIALINDEX(R)
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*** DIALINDEX search results display in an abbreviated ***
*** format unless you enter the SET DETAIL ON command. ***
?s market and depth and (price or prices) and (dynamic or moving) and diplay and (trade
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>>>No files selected.  Use SET FILES to choose at least two files; then use
        SELECT alone to reissue this SELECT statement.
?sf all
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              8    16: Gale Group PROMT(R)_1990-2004/Jan 13
              5    20: Dialog Global Reporter_1997-2004/Jan 13
              5    47: Gale Group Magazine DB(TM)_1959-2004/Jan 05
              3    75: TGG Management Contents(R)_86-2004/Jan W1
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              6    88: Gale Group Business A.R.T.S._1976-2004/Jan 13
              1    98: General Sci Abs/Full-Text_1984-2003/Nov
              5   141: Readers Guide_1983-2003/Nov
             22   148: Gale Group Trade & Industry DB_1976-2004/Jan 13
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             11   180: Federal Register_1985-2004/Jan 12
              1   211: Gale Group Newsearch(TM)_2004/Jan 12
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              3   262: CBCA Fulltext_1982-2004/Jan
              9   275: Gale Group Computer DB(TM)_1983-2004/Jan 13
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Examined 250 files
              1   436: Humanities Abs Full Text_1984-2003/Nov
              7   484: Periodical Abs Plustext_1986-2004/Jan W1
              4   485: Accounting & Tax DB_1971-2004/Jan W1
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              2   619: Asia Intelligence Wire_1995-2004/Jan 12
Examined 350 files
              2   636: Gale Group Newsletter DB(TM)_1987-2004/Jan 13
            120   654: US Pat.Full._1976-2004/Jan 08
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Examined 400 files
              1   727: Canadian Newspapers_1990-2004/Jan 13
              1   759: Reuters Business Insight_1992-2003/Dec
      Examined 450 files
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              2   990: NewsRoom Current Oct_2004/Jan 13
              2   992: NewsRoom Current_2003/Sep 30
              5   993: NewsRoom 2002
              1   994: NewsRoom 2001
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   31 files have one or more items; file list includes 485 files.

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     $3.02  TELNET
    $23.53  Estimated cost this search
    $23.67  Estimated total session cost  10.417 DialUnits
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(c) 2004 ProQuest Info&Learning
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         2827068  SCREEN
         3360396  DISPLAY
         2086990  DEPTH
         4266044  BID
         4417600  ASK
        11509588  TRADE
         5084739  TRADING
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>>>    started at PD=107280 stopped at PD=940522
Processing
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>>>    started at PD=830806 stopped at PD=970817
Processed  30 of  31 files ...
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Processing
Completed processing all files
             293  S1
        39158887  PD<2001
      S2      26  S1 AND PD<2001
```